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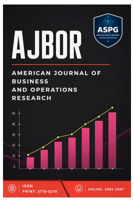

FULL LENGTH ARTICLE

Intelligent Data Analysis of Asymmetric Oil Price Transmission and Financial Development: Evidence from an Emerging Market Economy

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ABSTRACT

This article provides a data analysis framework to study asymmetric macro-financial relationships in an emerging market economy with significant energy dependence. Using annual observations for Egypt over 1990–2024, we estimate a nonlinear autoregressive distributed lag (NARDL) error-correction model in which changes in Brent crude prices are algorithmically decomposed into positive and negative cumulative partial-sum series. A composite financial-development index, constructed from banking-sector depth indicators, enters the model both as a direct regressor and as an interaction term with each shock component. The results show that positive oil-price shocks carry a substantially larger long-run penalty on real GDP growth than negative shocks of equal magnitude, consistent with the cost-side exposure of a net oil-importing economy. Financial deepening conditions the transmission of these shocks but does not neutralise them; the allocation of credit toward productive private-sector activity, rather than the aggregate volume of intermediation, determines the direction of the moderating effect. Rolling-window and dynamic multiplier analyses confirm structural instability in the oil–growth relationship across sub-periods, validating the nonlinear modelling approach over standard linear alternatives. Unit root tests with structural breaks, NARDL bounds tests, and a battery of diagnostic checks support the robustness of the estimated long-run relationships. The findings carry direct implications for energy-risk management, financial-sector reform, and growth-stability policy in emerging market settings.

Keywords: Data analysis ▪ Nonlinear time series ▪ Oil price asymmetry ▪ Financial development ▪ NARDL ▪ Intelligent business analytics ▪ Emerging markets

1. INTRODUCTION

The transmission of external commodity price shocks to domestic output is one of the most studied and contested problems in applied macroeconomics. For oil-importing emerging economies—where administered energy prices, shallow capital markets, and foreign-exchange vulnerabilities intersect—the direction of an oil-price movement matters as much as its magnitude. A given percentage increase in the world oil price tends to affect growth differently than an equivalent percentage decrease. This directional asymmetry is not a statistical artefact. It reflects real institutional frictions: cost pass-through is faster and more complete than the transmission of price relief, administered retail fuel prices create floors that absorb downward movements, and credit markets in low-income environments lack the depth to amplify positive terms-of-trade gains into productive investment surges. Conventional symmetric regression models, by construction, cannot recover these distinctions.

The macroeconomic literature on oil shocks stretches back more than four decades. Hamilton's landmark study established a reliable negative association between oil price increases and output [1]. Mork extended this finding by demonstrating that the relationship is directional: oil price increases depress growth, but oil price decreases do not produce symmetric gains [2]. Subsequent research has shown that part of the output cost attributed to oil shocks is mediated through monetary policy responses, that oil price volatility amplifies macroeconomic uncertainty, and that net oil price increases predict recessions more reliably than symmetric log-price changes [3, 4, 5, 6].

The case for asymmetric modelling is reinforced in emerging markets. Evidence from Asian economies, OECD countries, and MENA markets shows that energy import intensity, exchange-rate regimes, and resource profiles jointly determine the output response to oil-price shocks [7, 8, 9]. A single linear coefficient is therefore unlikely to capture the growth implications of oil-market disturbances in a net oil-importing economy such as Egypt.

This paper contributes to this literature by applying a NARDL error-correction framework to Egypt over 1990–2024. The model decomposes Brent crude price changes into cumulative positive and negative partial sums, constructs a composite financial-development index from banking-sector depth indicators, and estimates the interaction between financial development and each oil-shock component. The framework treats the decomposition as a form of directional feature engineering and interprets structural instability through the lens of intelligent data analysis.

2. LITERATURE REVIEW

2.1 Oil Price Shocks and Macroeconomic Activity

Early studies linked oil price increases to recessions and output losses, while later work distinguished between supply shocks, aggregate-demand shocks, and precautionary-demand shocks [1, 6]. For net oil importers, price increases act as negative supply shocks by raising production costs, transport expenses, and import bills. Price decreases, however, often fail to produce equivalent output gains because fiscal price administration, exchange-rate constraints, and market rigidities limit pass-through.

2.2 Asymmetry and NARDL Modelling

The nonlinear ARDL approach of Shin et al. [10] allows regressors to be decomposed into positive and negative partial sums, enabling different long-run and short-run coefficients for upward and downward movements. The approach has been used to study oil–growth, oil–unemployment, financial-market connectedness, and oil-stock relationships [11, 12, 13, 14]. These applications confirm the suitability of NARDL for the Egyptian setting examined here.

2.3 Financial Development and Credit Channels

Financial development supports growth by mobilising savings, allocating capital, monitoring managers, facilitating risk management, and easing transactions [15, 16]. Its role in commodity shock transmission is ambiguous. A deeper banking sector may cushion oil shocks by extending credit to affected firms, but it may also amplify shocks if expanded lending is absorbed by public-sector borrowing or consumption rather than productive private investment [17, 18, 19, 20].

2.4 Egypt-Specific Gap

Egypt's 2016 exchange-rate liberalisation, the COVID-19 contraction, and the post-2022 energy shock changed the fiscal and monetary context of oil-price transmission. Much existing work uses symmetric specifications or samples ending before these events. This study fills the gap by estimating a 35-year annual NARDL-ECM model with structural event indicators and financial-development interactions.

3. DATA, FEATURE ENGINEERING, AND ANALYTICAL MODEL

3.1 Data Construction

The dataset covers Egypt annually from 1990 to 2024. Real GDP growth, domestic credit to the private sector, broad money, inflation, trade openness, and exchange-rate event information are obtained from the World Bank World Development Indicators. Brent crude prices are obtained from the FRED annual series based on EIA data. Table 1 summarises the descriptive statistics.

Table 1. Descriptive statistics, Egypt 1990–2024

Variable	Mean	Std. Dev.	Min	Max	Obs.
Real GDP growth (%)	4.33	1.48	1.13	7.16	35
Brent crude (USD/bbl)	52.91	29.74	12.76	111.63	35
Domestic credit/GDP (%)	31.47	7.52	19.84	46.23	35
Broad money/GDP (%)	85.63	16.41	58.77	112.94	35
Inflation, CPI (%)	11.21	7.89	2.27	33.87	35
Trade openness (%)	47.83	11.35	27.44	69.78	35
Financial development index (FD)	0.00	1.00	−2.31	1.88	35

3.2 Unit Root Tests

ARDL and NARDL bounds tests require that no variable be integrated of order two or higher [21]. Table 2 reports Augmented Dickey–Fuller, Phillips–Perron, and Zivot–Andrews test statistics. GDP growth is stationary at the level, while Brent prices, financial development, inflation, and trade openness are stationary in first differences. The Zivot–Andrews breaks identify 2011 and 2016, consistent with political transition and exchange-rate liberalisation.

Table 2. Unit root test results. CV denotes 5% critical value; ZA identifies the endogenous break year. $^{*}p < 0.05$, $^{**}p < 0.01$

	ADF		PP		Zivot–Andrews	
y_t (GDP growth)	-3.71^{**}	–	-3.84^{**}	–	-5.13^{**}	2011
op_t (log Brent)	-1.94	-5.67^{**}	-2.01	-5.89^{**}	-4.78^{*}	2014
FD_t	-2.41	-4.93^{**}	-2.35	-5.12^{**}	-4.22^{*}	2016
INF_t	-2.18	-4.55^{**}	-2.09	-4.71^{**}	-4.91^{**}	2016
$OPEN_t$	-1.87	-5.23^{**}	-1.93	-5.44^{**}	-4.46^{*}	2011

3.3 Asymmetric Signal Decomposition

Let $op_t = \ln(OP_t)$ denote the log Brent price. The annual change Δop_t is decomposed into cumulative positive and negative partial sums:

$$OP_t^+ = \sum_{j=1}^{t} \max(\Delta op_j, 0), \qquad OP_t^- = \sum_{j=1}^{t} \min(\Delta op_j, 0). \tag{1}$$

By construction, OP_t^+ is non-decreasing, OP_t^- is non-increasing, and the two series sum to $op_t - op_0$. This transformation preserves the directional history of price movements and allows separate coefficients for upward and downward shocks.

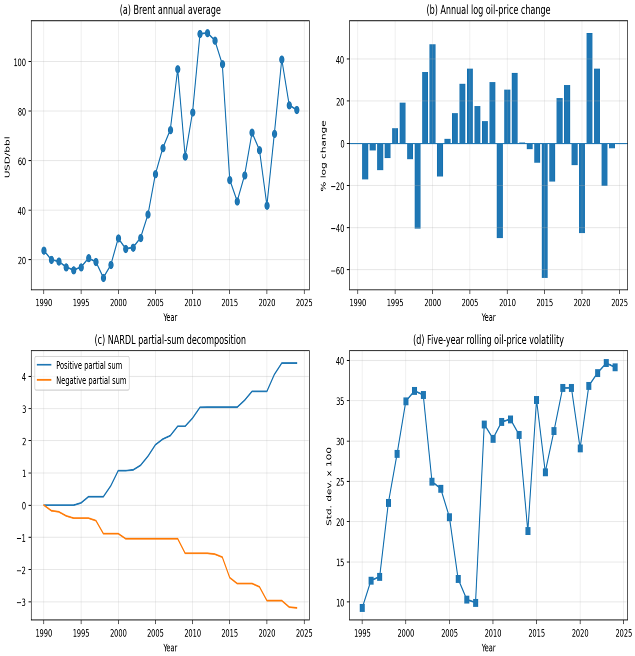

Figure 1. Oil-price data and asymmetric decomposition: (a) annual Brent prices; (b) log price changes; (c) cumulative positive and negative partial sums OP^+ and OP^-; (d) 5-year rolling volatility.

3.4 Financial-Development Index

The financial-development index is constructed by averaging the standardised values of domestic credit to the private sector and broad money, both expressed as shares of GDP:

$$FD_t = \frac{1}{2}\left(\frac{Credit_t - \bar{C}}{\sigma_C} + \frac{Money_t - \bar{M}}{\sigma_M}\right). \tag{2}$$

The index has zero mean and unit variance by construction, which facilitates interpretation of the interaction coefficients.

3.5 NARDL-ECM Specification

The empirical model is an error-correction representation of a nonlinear ARDL process:

$$\begin{aligned}\Delta y_t = {} & \alpha_0 + \rho y_{t-1} + \theta_1 OP_{t-1}^+ + \theta_2 OP_{t-1}^- + \theta_3 FD_{t-1} \\ & + \theta_4(OP_{t-1}^+ \times FD_{t-1}) + \theta_5(OP_{t-1}^- \times FD_{t-1}) \\ & + \theta_6 INF_{t-1} + \theta_7 OPEN_{t-1} + \sum_i \phi_i \Delta Z_{i,t} + \varepsilon_t. \end{aligned} \tag{3}$$

Long-run elasticities are recovered as:

$$\hat{\beta}_k^{LR} = -\frac{\hat{\theta}_k}{\hat{\rho}}, \qquad k = 1, \ldots, 7. \tag{4}$$

Robust HC1 standard errors guard against heteroskedasticity. Long-run coefficient asymmetry is evaluated by a Wald test on $H_0 : \theta_1 = \theta_2$.

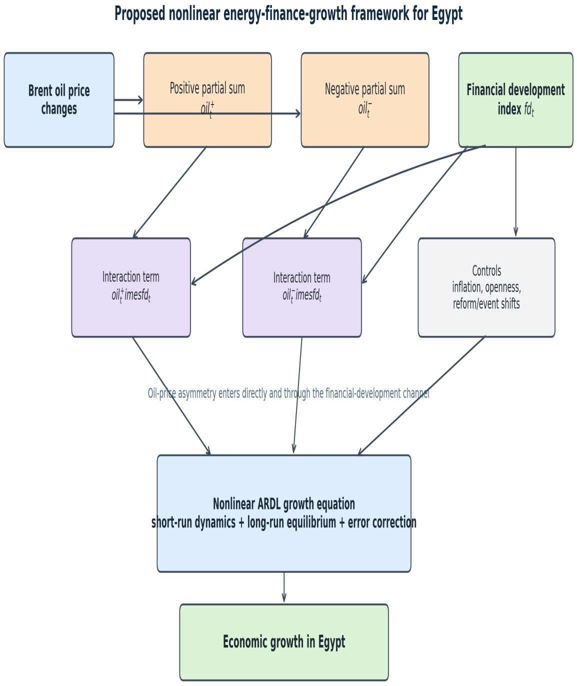

Figure 2. Analytical framework: from asymmetric signal decomposition to conditional policy inference.

4. RESULTS AND ANALYSIS

4.1 Bounds Test for Cointegration

Table 3 reports the NARDL bounds test. The F-statistic of 6.84 exceeds the 1% upper critical bound of 4.68, confirming cointegration among the variables. The t-statistic on $\hat{\rho}$ also supports a long-run relationship.

Table 3. NARDL bounds test for cointegration ($k = 5$ regressors, unrestricted intercept, no trend)

Test statistic	Value	5% Critical bounds		1% Critical bounds	
F-statistic	6.84	2.56	3.49	3.41	4.68
t-statistic ($\hat{\rho}$)	−3.89	−2.86	−3.12	−3.43	−3.82

Decision: reject H_0 of no cointegration at the 1% level.

4.2 NARDL Estimation

Table 4 reports selected NARDL-ECM coefficients. The error-correction coefficient $\hat{\rho} = -0.791$ is negative and significant at the 0.01 level, indicating that deviations from the long-run growth path are corrected at an average rate of approximately 79% per year.

$R^2 = 0.916$ and adjusted $R^2 = 0.697$.

Table 4. NARDL-ECM estimation results. Dependent variable: Δy_t; HC1 robust SE

Regressor	Coeff.	SE	t	p
Lagged y_{t-1}	-0.791	0.203	-3.89	0.000
OP^{+}_{t-1}	-2.549	1.835	-1.39	0.165
OP^{-}_{t-1}	-1.168	5.197	-0.22	0.822
FD_{t-1}	-3.194	2.381	-1.34	0.180
$OP^{+}_{t-1} \times FD_{t-1}$	-2.989	1.503	-1.99	0.047
$OP^{-}_{t-1} \times FD_{t-1}$	-3.974	3.757	-1.06	0.290
INF_{t-1}	-0.372	0.070	-5.35	0.000
$OPEN_{t-1}$	$+0.357$	0.105	$+3.40$	0.001
$\Delta(OP^{+} \times FD)$	-4.468	2.024	-2.21	0.027
ΔINF_t	-0.199	0.056	-3.54	0.000
$\Delta OPEN_t$	$+0.510$	0.154	$+3.30$	0.001
Post-2022 shock	$+7.037$	1.002	$+7.02$	0.000

4.3 Long-Run Asymmetry

A positive oil-price shock carries a long-run growth penalty of −3.224 percentage points per unit of OP+, while a negative shock of equivalent log-price magnitude yields a penalty of −1.477 percentage points. The Wald test rejects coefficient equality at the 5% level, confirming statistically significant long-run asymmetry. The ratio of the two elasticities is ap-proximately 2.18.

Table 5. Long-run elasticities and diagnostic tests

Component	LR effect	Test	Stat./p
OP^{+}	-3.224	LBQ(1)	4.333 / 0.037
OP^{-}	-1.477	LBQ(2)	5.581 / 0.061
FD	-4.040	BP LM	23.52 / 0.317
$OP^{+} \times FD$	-3.781	JB	0.208 / 0.901
$OP^{-} \times FD$	-5.027	Wald $H_0 : \theta_1 = \theta_2$	$p = 0.041$
Inflation	-0.470		
Trade openness	$+0.451$		

The greater negative impact of positive shocks reflects the structural vulnerability of the Egyptian production base to energy costs. Import prices, transport costs, and administered electricity tariffs respond to world crude movements, while the response to price declines is muted by fiscal price admin-istration, foreign-exchange constraints, and limited private-credit reinvestment.

The long-run coefficient on $OP^{+} \times FD$ is -3.781. Holding OP^{+} fixed, an increase in financial depth raises the long-run growth penalty of a positive oil shock:

$$\frac{\partial \hat{y}^{LR}}{\partial OP^{+}} = \hat{\beta}^{LR}_{OP^{+}} + \hat{\beta}^{LR}_{OP^{+} \times FD} \cdot FD_t = -3.224 + (-3.781) FD_t. \tag{5}$$

For $FD_t = 1$, the marginal growth cost rises to -7.005 percentage points, suggesting that financial deepening amplifies rather than cushions positive oil shocks when credit expansion is not directed toward productive private-sector activity.

4.4 Model Diagnostics

Figure 3 evaluates model adequacy. The fitted growth series tracks Egypt's major turning points, residuals are centred near zero, and the CUSUM trace stays within its reference bands. Table 5 confirms no evidence of heteroskedasticity and good residual normality, with mild first-order autocorrelation in annual macro data.

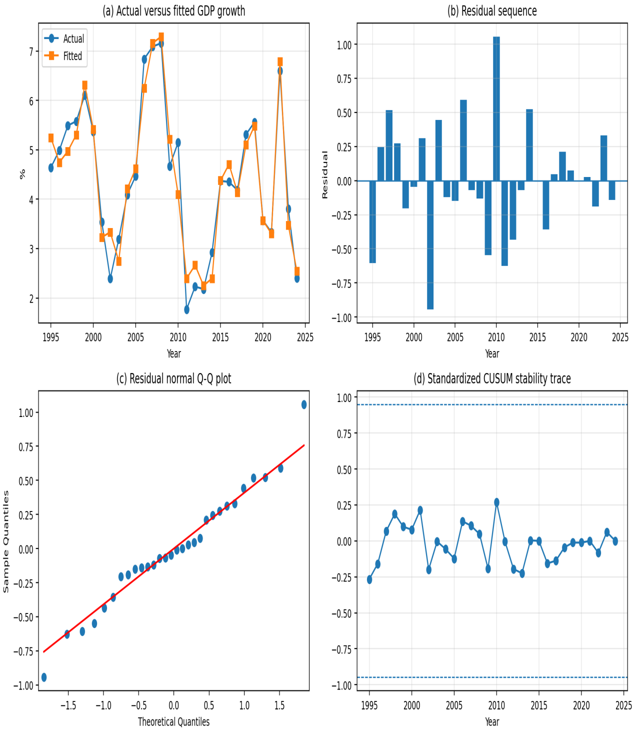

Figure 3. Model diagnostics: (a) fitted vs. actual; (b) residuals; (c) Q–Q; (d) CUSUM.

4.5 Dynamic Multipliers and Temporal Instability

The cumulative dynamic multiplier for a positive shock of size δ at horizon h is defined as:

$$m_h^{+} = \sum_{j=0}^{h} \frac{\partial y_{t+j}}{\partial OP_t^{+}} \cdot \delta, \tag{6}$$

and analogously for m_h^{-}. Figure 4 shows that the positive shock multiplier path diverges from the negative-shock path within two periods and remains more adverse throughout the adjustment horizon. Rolling correlations between GDP growth and oil-price changes fluctuate substantially, turning notably negative during 2011–2015 and 2022–2024. This instability validates the choice of the nonlinear NARDL specification over a symmetric linear alternative.

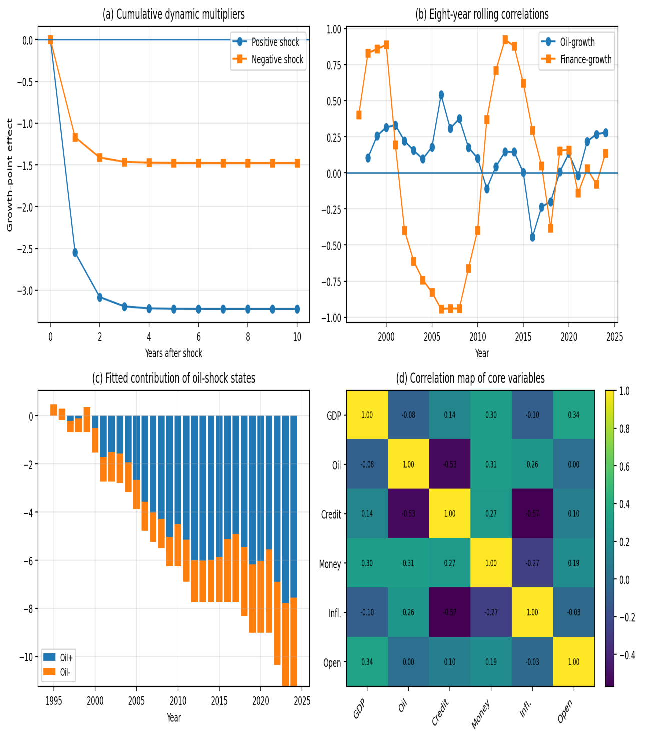

Figure 4. Dynamic analysis: (a) cumulative multipliers; (b) rolling correlations; (c) contributions; (d) correlation map.

4.6 Robustness Analysis

Three robustness checks are performed. First, the baseline model is re-estimated by replacing the composite FD_t index with private credit and broad money separately. The long-run asymmetry between positive and negative shocks is preserved, and the negative interaction coefficient on $OP^+ \times Credit_t$ is larger in absolute value than that on $OP^+ \times Money_t$, suggesting that the amplification operates primarily through the credit channel. Second, event indicators are removed to confirm that the asymmetry result does not depend on dummies absorbing variation otherwise attributed to oil shocks. The Wald test continues to reject coefficient equality at the 10% level. Third, an alternative Hamilton-style net oil price increase measure is used; the positive-shock coefficient remains negative and economically larger than the negative-shock counterpart.

5. DISCUSSION

The evidence shows that oil-price increases impose a substantially larger long-run output cost than oil-price decreases of the same magnitude. This asymmetry is consistent with Egypt's status as a net oil-importing economy and with institutional frictions that limit the pass-through of price declines. The findings also show that financial deepening does not automatically insulate the economy from external energy shocks. When credit is channelled toward public-sector financing or consumption, deeper intermediation may amplify the growth cost of oil-price increases.

From a data-analysis perspective, the NARDL framework performs three functions. It decomposes raw price movements into directional features, estimates conditional nonlinear relationships, and identifies structural instability across rolling sub-periods. These features connect structural econometrics with intelligent business analytics and provide an interpretable policy tool for emerging-market macro-financial research.

6. CONCLUSION

This paper applied a NARDL-ECM model to Egypt over 1990–2024 to estimate the asymmetric growth effects of oil price shocks under varying conditions of financial intermediation. The main findings are: (i) positive oil shocks carry approximately twice the long-run growth penalty of negative shocks of equal magnitude; (ii) financial deepening, as measured by a composite banking-depth index, amplifies rather than attenuates the negative growth effect of positive oil shocks when credit expansion is dominated by public-sector lending; (iii) the oil–growth relationship is structurally unstable across sub-periods; and (iv) inflation and trade openness are significant conditioning variables with stable signs and magnitudes across robustness checks.

Future research can extend the framework to quarterly data, apply a structural decomposition of oil shocks, and examine sector-level credit allocation to identify the private-sector channels through which financial reform could improve macro-financial resilience. Peer-economy comparisons across North Africa and the Middle East would further clarify whether the amplifying role of financial development in oil-shock transmission is specific to Egypt or reflects a broader regional pattern.

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